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(54) **Electrophoretic display device.**

(57) An electrophoretic display device is described where a set of anode electrodes (7, 7') in an electrophoretic cell are disposed opposite row and column electrodes (5, 6) at a second side of the electrophoretic cell. The anode electrodes (7, 7') encompass equal pluralities of at least the row electrodes (6), and such equal pluralities of electrodes (6) are connected in parallel. This significantly reduces the number of drivers and leads to the display.

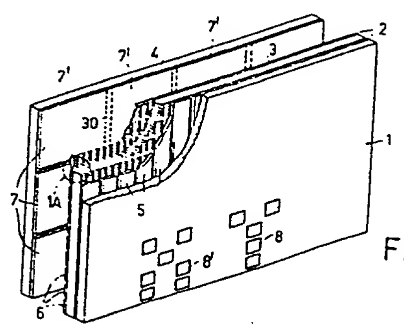

FIG.1

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Croydon Printing Company Ltd

"Electrophoretic display device".

The present invention relates to an electrophoretic display device comprising first and second oppositely disposed substrates with at least one of said substrates being transparent, an electrophoretic fluid containing a plurality of charged pigment particles disposed between said first and second substrates, first electrode means comprising a plurality of first electrodes disposed at a facing surface of said first substrate, second electrode means comprising a plurality of second electrodes disposed on a dielectric structure adjacent to said first electrode means, and third electrode means disposed on a facing surface of said second substrate.

Electrophoretic display devices are generally non-emissive field-effect display devices. They generally lack a suitable threshold in the brightness versus voltage characteristic, and accordingly, simple cross-bar matrix addressing methods are not applicable. Matrix addressing has been made practical by the incorporation of a third control grid electrode in the device structure, such as may be seen in U.S. Patent No. 4,203,106 to Singer and Dalisa. In such structures it is possible to access M x N display elements with M + N + 1 electrical leads and their associated drivers.

In order to more practically control and address electrophoretic matrix type displays, and to reduce the cost of drive electronics, it is required to effectively reduce the number of electrode leads and/or drivers in the electrophoretic matrix display device.

It is an object of the present invention to provide an electrophoretic matrix display device of

a construction which enables a significant reduction in the number of leads and/or drivers in large matrix devices.

It is another object of the present invention to provide an electrophoretic display construction which has the possibility of selective erasure and rewriting.

According to the present invention an electrophoretic display device comprising first and second oppositely disposed substrates with at least one of said substrates being transparent, an electrophoretic fluid containing a plurality of charged pigment particles disposed between said first and second substrates, first electrode means comprising a plurality of first electrodes disposed at a facing surface of said first substrate, second electrode means comprising a plurality of second electrodes disposed on a dielectric structure adjacent to said first electrode means, and third electrode means disposed on a facing surface of said second substrate is characterized in that said third electrode means comprises a plurality of third electrodes.

By means of a plurality of third electrodes the structure of the present invention enables electrophoretic writing to be accomplished in only that portion of the structure opposite an enabled third, or anode, electrode. When means are provided for applying an enabling voltage bias value on at least one of the third electrodes while maintaining a non-enabling voltage bias value on the remaining ones of the third electrodes, the structure in effect represents a three input AND-gate analog since a response is obtained only when all three electrodes are addressed. By this arrangement, the magnitude of the unenabled (third electrode) anode bias is made such as to prevent transport of pigment from the control grid structure (first and second electrodes) to the anode even though the voltages on the first and second electrodes would normally allow it. On the other

hand, the anode (third electrode) bias voltage is such as to prevent the return of pigment already on the anode to the control grid structure. This prevents unwanted erasure once writing has been accomplished. Consequently, regardless of the addressing voltages applied to the first and second electrodes opposite third electrodes which are not enabled, writing will not occur. However, when a third electrode is enabled, writing will occur normally.

Consequently an electrophoretic display device in accordance with the present invention enables a reduction of at least the number of drivers. The plurality of first electrodes may be divided into groups of electrodes having the same number of electrodes per group. With each of the third electrodes being opposite to a group of first electrodes, each electrode of a group may be connected to one electrode of each other group. The electrodes so interconnected may be coupled to a respective input terminal. The interconnection of electrodes may be outside or inside the display device. An interconnection inside the display device has the advantage that in that case also the number of leads is significantly reduced.

It is also possible to divide the second electrodes into groups, each having the same number of electrodes per group. In that case each of the third electrodes is opposite to a respective group of second electrodes. According to a further embodiment both the first and second electrodes may be divided into groups with each of the third electrodes being opposite to a respective group of first electrodes and a respective group of second electrodes. Such a construction may result in a further reduction of the number of drivers and/or leads.

These various aspects of the present invention

may be further understood by reference to the accompanying drawing figures which provide various examples without limitation, and wherein,

Figure 1 illustrates the structure of the present invention,

Figure 1a illustrates a portion of the structure of Figure 1, and

Figure 2 illustrates the driving circuitry utilized in connection with the present invention.

An embodiment of the electrophoretic display device of the present invention may be seen, for example, by reference to Figure 1. The electrophoretic display device involves two separated substrates 1 and 4, at least one of which is transparent by way of being a material such as glass or plastic. The control grid structure 2 involves a dielectric structure 3 having multiple holes throughout its surface in a regular configuration. A detail of the control grid structure 2 with second electrodes as row electrodes 6 can be seen in Figure 1a. The row electrodes 6 are formed at one side of the dielectric layer 3, and at an opposite side of the dielectric layer 3, are first electrodes as column electrodes 5 transverse to the row electrodes 6.

Separated from the row electrodes 6 in the structure are the third electrodes as anode electrodes 7 which are shown, for example, in the drawing figure as extending transversely in parallel strips. An insulating structure (not shown) typically maintains the separated substrates and internal structure of electrodes and electrophoretic solution in a single structure.

In the structure illustrated in Figure 1, the anode electrodes 7 consist of three individual electrode strips which are exactly opposite three groups of four row electrodes in the control structure. If the first, fifth, and ninth row electrodes are connected in parallel, as are the second, sixth, and tenth row electrodes, the third, seventh, and eleventh row electrodes, and the

fourth, eighth, and twelfth row electrodes, there will only be four external row leads. Consequently, the number of anode leads have increased from one to three, but the number of row leads has decreased from twelve to four with a net saving of six leads. The interconnection of electrodes 6 is preferably inside the display device.

In operation, one of the anodes 7 would be enabled while the other two anodes would be held at the prevent level. The address pulse would appear on the row lead connected to the first, fifth and ninth row electrodes for a time t_r and the column information would appear on all column electrodes simultaneously during the time t_r. Writing would occur in the first row electrode, and because the other two anode electrodes are not enabled, writing cannot occur in the fifth and ninth row electrodes. The address pulse would appear sequentially on the row lead connected to the second, sixth, and tenth row electrodes, and thereafter on the third, seventh and eleventh row electrodes, and subsequently the fourth, eighth and twelfth row electrodes for a time t_r with new column information being presented for each row.

Consequently, after $4t_r$, writing would have occurred in the first four row electrodes. Then another anode 7 would be enabled while the remaining anodes 7 would be at the prevent level. In this arrangement, four address pulses of duration t_r each would be applied sequentially to the four external row leads. Therefore, after $8t_r$ a total of eight rows will have been written. The process is then repeated with the final anode electrode 7 being enabled so that writing is completed in $12t_r$, which is the same time required for the standard device.

In operation, the anode voltage could be provided at enabling voltage levels (50 Volts) or preventing voltage levels (10 Volts). These levels would enable writing to occur so as to provide written images,

such as 8 and 8' seen in Figure 1 which represent enabling of the lower anode 7. With respect to the display device several modifications are possible. The words "row" and "column" are only used to distinguish between two coordinate lines. Consequently the word "row" may include other directions than "horizontal" and the word "column" may include other directions than "vertical". The coordinate lines may extend at any desired angle, for example 90°, to each other. Thus either of the two groups of coordinate lines of the electrodes can be termed "row" electrodes with the electrodes of the other group being termed "column" electrodes. Furthermore the electrodes 5 in Figure 1 may be row electrodes parallel to electrodes 7 and the electrodes 6 may be column electrodes perpendicular to electrodes 5 and 7.

According to a further embodiment said third electrodes 7 may be arranged according to a matrix of electrodes 7' (denoted by dotted lines 30) with each electrode 7' encompassing an area corresponding to the overlapping area of both a respective group of electrodes 5 and a respective group of electrodes 6. In that case certain criteria need be followed in order to obtain a matrix addressed control grid electrophoretic device with a practical minimum number of leads. In the instance where the reduction is the result of reducing both the number of row leads and the number of column leads, the following criteria may be observed. Namely, if X equals the number of external column leads, Y equals the number of external row leads, C equals the number of column electrodes, and R equals the number of row electrodes, then m can be taken to be equalto C/X which is equal to the number of vertical divisions of the anode. Further n can be taken to be equal to R/Y which is equal to the number of horizontal divisions of the anode.

To make a practical drive circuit, X should be a multiple of the number of column electrodes in the character plus the space between characters, and Y should

be a multiple of the number of row electrodes in the character plus the space between lines.

In a RxC matrix, the number of anode leads is (m).(n) and the total number of leads is (m).(n) + X + Y. It is this total that is minimized. A trial and error procedure is utilized to minimize the total number of leads.

This procedure is to write the factors of R which are multiples of Y in a list of ascending order of n, and make a similar list for the factors of C which are multiples of X in an ascending order of m. Values of m and n which are near the middle of a list are then chosen so that the total number of leads (m).(n) + X + Y are calculated. Finally, other nearby values for m and n are chosen until the combination which gives the lowest total is found.

In an example 24 lines of text with 60 characters per line in a 7 by 9 format with 2 rows between lines of characters and 2 columns between characters are provided. This results in a 540 by 264 matrix which would require 805 leads and drivers for the standard device. Table 1 gives (m).(n) + X + Y for all values of m and n. The minimum occurs for m equal 10 (X equal 54) and n equal 6 (Y equals 44) and is158. This is a reduction in the number of leads, and drivers of greater than 80%.

Table 1: (m).(n) + X + Y equal total leads.

	n =	2	3	4	6	8	12	24
	Y =	132	88	66	44	33	22	11
m =	X =							
2	270	406	364	344	326	319	316	329
3	180	318	277	258	242	237	238	263
4	135	275	235	217	203	200	205	242
5	108	250	211	194	182	181	190	238
6	90	234	196	180	170	171	184	245
10	54	206	172	160	158	167	196	305
12	45	201	169	159	161	174	211	344
15	36	198	169	162	170	189	238	407
20	27	199	175	173	191	220	289	518
30	18	210	196	204	242	291	400	749
60	9	261	277	315	413	522	751	1460

The drive electronics for the present invention may be considered in Figure 2. As an example, a display having 40 lines of 32 characters each is provided in Figure 2. Prior to writing, the display must be conditioned by the erase signal 10 in conjunction with the sequencing circuit 11 and the row driver 12, column driver 13, and anode driver 14 feeding the electrophoretic display device 27. The sequence is erase, set and hold, which leaves the row electrodes at the hold voltage and the anode at the prevent voltage level.

Character information 15 is continuously fed into the memory 16 along with an additional signal 17 for tone change information when required.

When the required number of characters to fill the first line of text has been received and counted by the character counter 18, writing of the first line may commence. Of course, character information may be still fed into the memory 16. A first anode n_1 is placed at the enable voltage level provided by the line enable circuit 26 through anode drive 14. The code for the first

character appears at the input to the character generator 19 and the row counter 20 tells the character generator 19 to present the column information for row Y_1 at its outputs. The parallel column information is fed into a parallel-input/serial-output shift register 21 to convert the parallel information into serial information. This serial information passes through a tone change circuit which is a controllable complimenter 22 to the input of a serial-input/parallel-output shift register 23 whose parallel output feeds the column drivers 13. When the clock signal from clock 24 has shifted enough bits for one character width, a signal is sent to the memory 16 telling it to present the code for the second character to the input of the character generator 19. This process continues until all of the column information for row Y_1 has entered the column drivers 13 by way of the shift register 23.

At this point the driver for row Y_1 is enabled with a voltage V_R, and the entire line of row Y_1 is written. After the time t_r required to write the row has passed, row Y_1 becomes non-selected. The process is now repeated for rows Y_2 through Y_8 until the entire line-of-text for line 1 is written. The process is then repeated for rows Y_9 through Y_{16} until line 2 is written. After line 2 is written, anode n_1 is placed at the prevent voltage level, and anode n_2 is enabled by the line enable circuit 26 so that the third and fourth lines of text can be written. This process continues until the entire display is written. Using this technique, each line of text is written as a simple matrix addressed cell, and while the process may appear long, everything except the actual transport of the pigment is done at electronic speeds. This drive scheme is similar to that required for the standard device, except that an additional voltage level (prevent) is provided to the anode.

The drive circuit for the case where the anode electrodes are divided vertically as well as horizontally,

would be similar to the circuit described above with some modifications. In this case, writing can now begin before the entire line of characters has been entered. After enough characters have entered the memory 16 to fill one line of one anode segment width, writing may commence for that section. After that segment is written, writing moves to the next anode segment, etc. The change required in the drive circuit is that the character counter 18 must now enable consecutive anode segments of a line of text as the data enters, instead of waiting for the entire line to fill. Thus, with this system, writing begins sooner. Since the appropriate columns are connected in parallel, the SIPO shift register 23 and the number of column drivers 13 are greatly reduced.

While various embodiments of the present invention have been described, it is not intended to limit the present invention to the specifically described embodiments, and all modifications suggested from the description of the invention are intended to be included.

CLAIMS

1. An electrophoretic display device comprising first and second oppositely disposed substrates with at least one of said substrates being transparent, an electrophoretic fluid containing a plurality of charged pigment particles disposed between said first and second substrates, first electrode means comprising a plurality of first electrodes disposed at a facing surface of said first substrate, second electrode means comprising a plurality of second electrodes disposed on a dielectric structure adjacent to said first electrode means, and third electrode means disposed on a facing surface of said second substrate, characterized in that said third electrode means comprise a plurality of third electrodes.

2. An electrophoretic display device as claimed in Claim 1, characterized in that said plurality of first electrodes is divided into groups of electrodes having the same number of electrodes per group, each electrode of a group being connected to one electrode of each other group and each of said third electrodes being in operative arrangement with a respective group.

3. An electrophoretic display device as claimed in Claim 1, characterized in that said plurality of second electrodes is divided into groups of electrodes having the same number of electrodes per group, each electrode of a group being connected to one electrode of each other group and each of said third electrodes being in operative arrangement with a respective group.

4. An electrophoretic display device as claimed in Claim 1, characterized in that said plurality of first electrodes is divided into first groups of electrodes each having a first number of electrodes per

group, each electrode of a first group being connected to one electrode of each other first group, said plurality of second electrodes is divided into second groups of electrodes each having a second number of electrodes per group, each electrode of a second group being connected to one electrode of each other second group, and each of said third electrodes being in operative arrangement with a respective first group and a respective second group.

5. An electrophoretic display device according to one of Claims 1, 2, 3 or 4, characterized in that said first electrodes are column electrodes and said second electrodes are row electrodes.

6. An electrophoretic display device according to one of Claims 1, 2, 3 or 4, characterized in that said first electrodes are row electrodes and said second electrodes are column electrodes.

7. An electrophoretic display device as claimed in Claim 5, characterized in that said third electrodes are row electrodes, each emcompassing an area corresponding to a respective group of at least said second row electrodes.

8. An electrophoretic display device as claimed in Claim 6, characterized in that said third electrodes are row electrodes, each emcompassing an area corresponding to a respective group of at least said first row electrodes.

9. An electrophoretic display device as claimed in Claim 4, characterized in that said first electrodes are column electrodes, said second electrodes are row electrodes and said third electrodes are arranged according to a matrix of electrodes, each third electrode emcompassing an area corresponding to the overlapping area of a respective group of said first electrodes and a respective group of said second electrodes.

10. An electrophoretic display device as claimed

in Claim 4, characterized in that said first electrodes are row electrodes, said second electrodes are column electrodes and said third electrodes are arranged according to a matrix of electrodes, each third electrode emcompassing an area corresponding to the overlapping area of a respective group of said first electrodes and a respective group of said second electrodes.

11. An electrophoretic display apparatus comprising, in combination, an electrophoretic display device as claimed in anyone of Claims 1 to 10, characterized in that the apparatus comprises means for alternatively applying an enabling voltage bias value on one of said third electrodes and means for maintaining a lower voltage bias value on remaining ones of said third electrodes.

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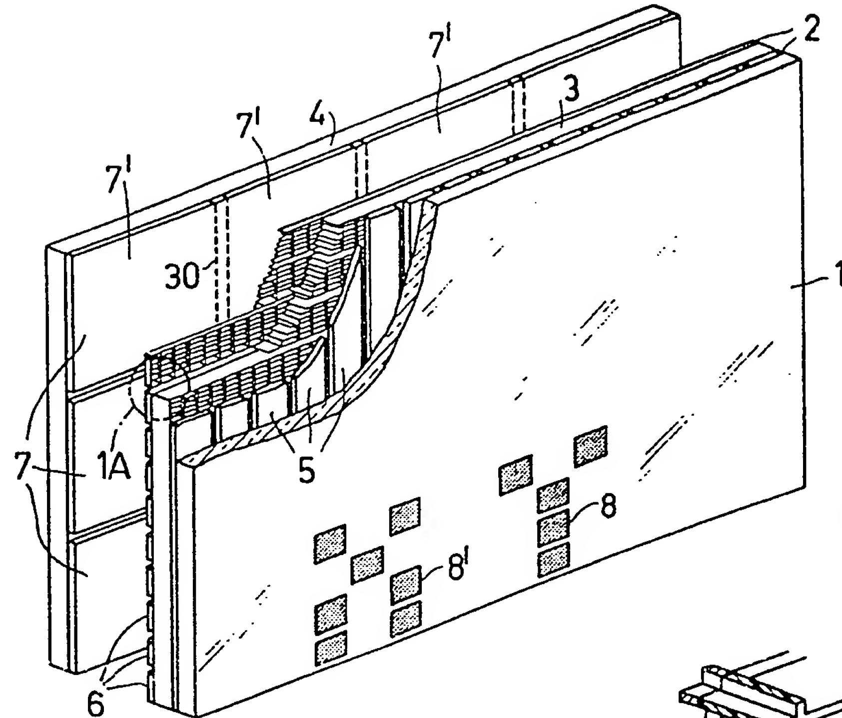

FIG.1

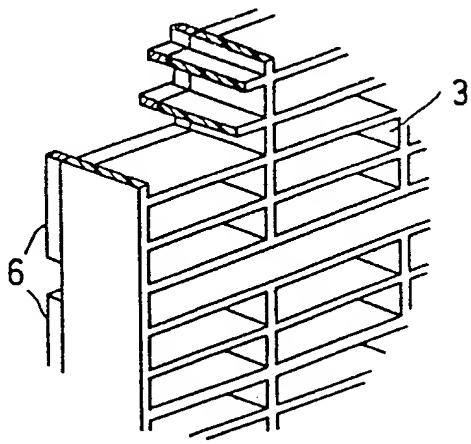

FIG.1A

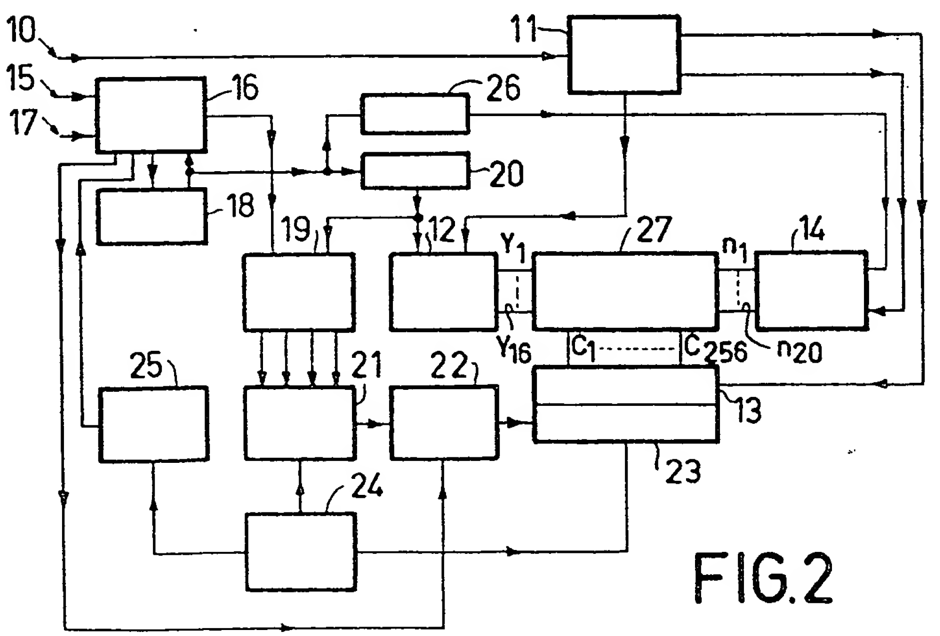

FIG.2